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RESEARCH ARTICLE

Acoustic monitoring of the hunting pressure over the wintering population of the Red-breasted Goose *(Branta ruficollis)* in Romania

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Abstract

This study explores the use of Passive Acoustic Monitoring (PAM) to assess the hunting pressure on the vulnerable Red-breasted Goose (*Branta ruficollis*) population wintering in Romania. The Red-breasted Goose is a long-distance migrant whose numbers have been declining, with south eastern Romania serving as a significant wintering area. Despite restrictions on hunting, the species remains vulnerable to accidental shooting and gunshot disturbances targeting Greater White-fronted Geese *(Anser albifrons)*, a legal quarry species that coexists in mixed flocks with the Red-breasted Goose. This research employed AudioMoth acoustic devices at three Natura 2000 sites during two winter seasons (2018–2020). The devices recorded over 5900 hours of sound data, detecting 2530 gunshots across 220 days. Results showed that the hunting pressure was highest at Balta Albă Lake, where 69% of study days recorded gunshots. The findings highlight that PAM is a cost-effective method for monitoring hunting activity, with potential applications for enforcing conservation measures and preventing poaching. The study concludes with recommendations for improving field data collection, data analysis, and implementing stronger conservation measures, such as hunting bans within critical areas for the Red-breasted Goose.

Keywords

Audiomoth, Geese, Gunshot, Dobrogea, Bărăgan.

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PENSOFT.

Introduction

The Red-breasted Goose is a long-distance migrant that breeds in Arctic Russia, mainly on the Taimyr, Gydan and Yamal peninsulas, but also nearby mainland (Hunter and Black 1996). It migrates south through Russia to Kazakhstan and then west through southern Russia to the north and west Black Sea coasts. Prior to the 1960's, the population wintered along western Caspian coasts, mainly in Azerbaijan, Iran and Iraq, but subsequently rapidly shifted to the Western Black Sea coast. (BirdLife International 2021). Nowadays, the majority of the population currently winters in Romania, Ukraine, and Bulgaria from December to February at 10–20 roost sites, but some individuals remains also in South Russia during mild winters (Cranswick et al. 2012). In 2015, Wetlands International increased its global population estimate from c. 44,000 to c. 56,000 individuals. The species is classified as vulnerable with a population trend in decline (BirdLife International 2017). The wintering numbers in Romania vary from 8,660 to 23,783 individuals exclusively distributed in the south-east part of the country (Fig. 1), Bărăgan and Dobrogea regions (Todorov et al. 2023).

The Red-breasted Goose is protected by the Romanian law species (OUG 57/2007). The southeast part of the country offers large water bodies which are used

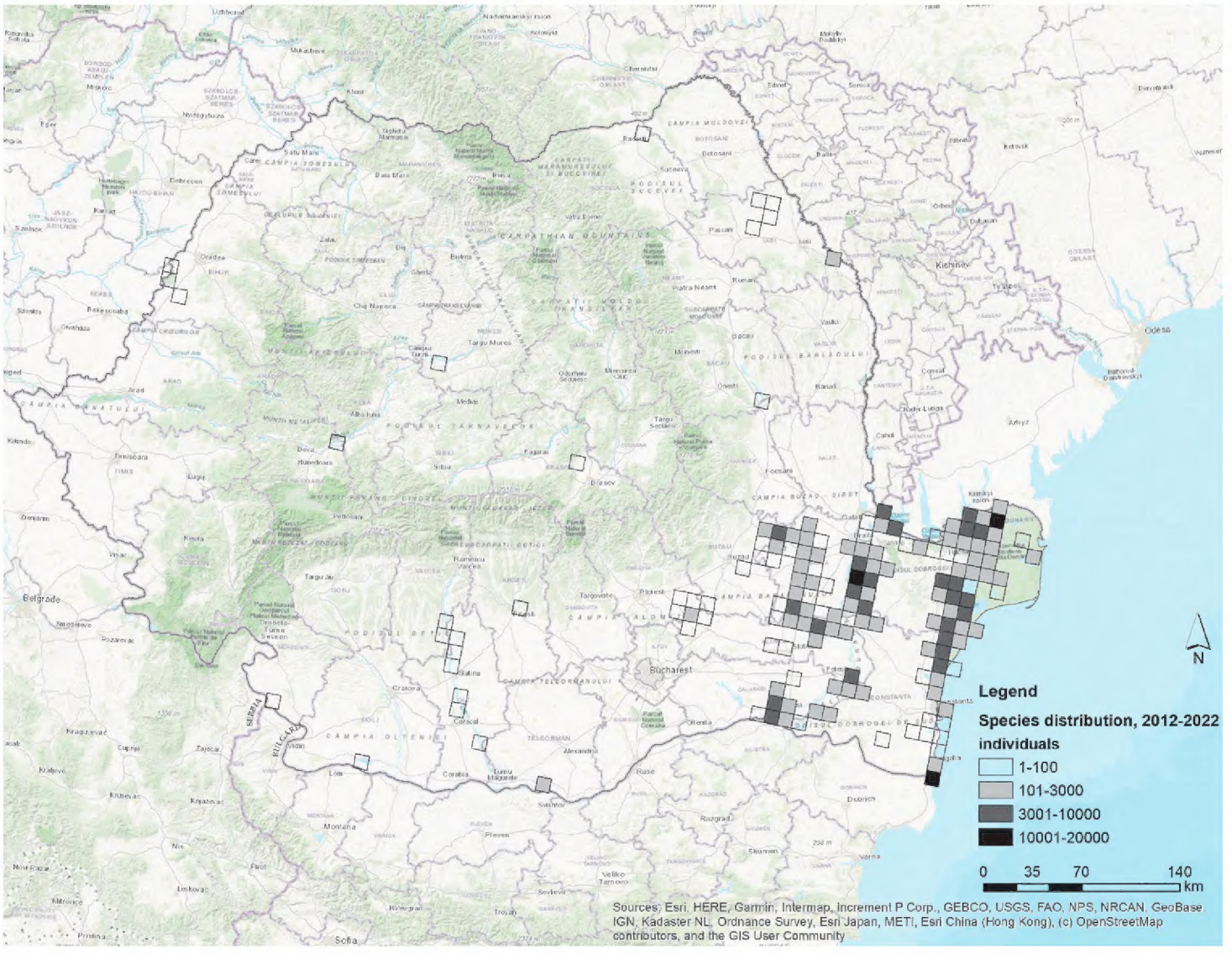

Figure 1. Distribution and numbers of the Red-breasted Goose in Romania during the period 2012–2022.

by the geese as roosts and vast crop fields used as foraging grounds. This makes the region an important wintering area also for the gregarious Greater White-fronted Goose, which is a legal quarry species and forms mixed flocks with the Red-breasted Geese when roosting and feeding. Hunting pressure is considered one of the main threats to Red-breasted Goose (Cranswick et al. 2012). Although the species is protected over its whole flyway, many of them are either accidental or deliberately killed. There is little quantitative information on the scale of mortality or to evaluate its impact; however, research in Bulgaria during 1995–2009 indicated that 3–5% of the Red-breasted Goose population is killed or injured by hunting each year (Cranswick 2012). Since 2017, there have been at least 3 officially reported cases to the responsible authorities of hunters who killed Red-breasted Geese (SOR 2025). There are also cases when hunters fire directly at flocks consisting only of Red-breasted Geese in good visibility conditions (SOR 2025). Apart from the direct mortality, the hunting activity produces very high levels of disturbance, which might seriously impact the species survival (Cranswick et al. 2012). Considerable disturbance may cause loss of feeding time, which may be critical, for example, during periods of severe weather or prior to migration. The long hunting season in some countries, for example, extending into late winter, is a particular cause of concern, as this affects the birds' ability to increase energy reserves prior to migration and breeding. Regular disturbance at these sites may result in increased energy expenditure by the birds and, in extreme cases, for the site to be abandoned (Bell and Owen 1990; Madsen and Fox 1995; Hirschfeld et al. 2019). Goose and duck hunting in southeast Romania is well known, both for locals and foreign hunters, mainly as a sport. In Romania, the majority of the goose hunting takes place at dawn and dusk within the foraging grounds from well-prepared hunting hides, but quite often hunters are shooting from the banks of the lakes where the geese are roosting, while the geese are taking off to their foraging grounds. Most of the roosting areas in the wintering range in Romania are within the special protected areas (SPA), part of the European ecological network Natura 2000. Hunting is permitted within the borders of the SPAs.

According to the hunting law (407/2006), the hunting of Greater White-fronted Geese is permitted for 123 days during 15 October and 15 February. The daily hunting quota per hunter is 10 geese. Covering the whole wintering range of the species in Romania by surveyors to detect the gunshot events is not feasible due to the extremely vast survey area, over 30,000 sq. km. Such an activity would require significant financial implication to cover the costs for many observers, vehicles, and equipment. However, efforts using observers who were appointed to count also the geese at their roosts were implemented in Romania during the winter season of 2018/2019. The results show hunting activity of average 1 hunter per 30 ha out of the 10,000 ha. In the 4 studied sites, 492 gunshots were fired. The intensity of the gunshots varied between 2 and 47 fires per hour. These results show that the hunting pressure seems to be very high and raise many questions regarding the sustainable hunting and the conservation of the threatened waterbirds in Romania (Iankov et al. 2021). However, empowering field observers with many tasks might lead to some data collection gaps, which might

affect the final results. In order to bring unbiased and clear results of understanding what are the levels of disturbance caused by the hunting activity within the protected areas over the wintering population of the Red-breasted Goose, we decide to start a Passive Acoustic Monitoring (PAM) program. Recently, PAM became widely used in ecological research, following the global trends of automated data collection. Using unattended sound recording, PAM provides tools for long-term and cost-effective biodiversity monitoring (Sugai et al. 2019). Using different PAM methods was successfully used in estimating the hunting activity over biodiversity (Astaras et al. 2017; Astaras et al. 2016; Kalmár et al. 2019; Wrege et al. 2017). Moreover, the PAM can serve as a tool for effective planning of the anti-poaching patrols, which are proven to be an effective way of monitoring wildlife law enforcement (Jachmann 2008; Linkie et al. 2015). In order to minimize poaching incidents within the protected areas important for the Red-breasted Goose, the General Association of the Hunters and Anglers introduced an anti-poaching patrolling scheme within the project "Life for Safe Flight" (LIFE16NATBG000847). However, the scheme failed to detect any poaching activity due to poor implementation in the period 2018–2019. In the following season, bird hunting was suspended in Romania, so no patrolling activities were implemented.

In this study, we are presenting our findings about the use of PAM as a tool for detecting the gunshot events produced from the hunting activity within the limits of the protected areas designated for the conservation of the vulnerable Red-breasted Goose in Romania. Our aim is to demonstrate that the PAM could be an effective tool that can contribute significantly to the assessment of the hunting pressures over the bird populations and limit poaching incidents.

Materials and methods

Study area

The study was conducted at three Natura 2000 sites, ROSPA0051 Iezerul Călărași, ROSPA0059 Lacul Strachina, and ROSPA0004 Balta Albă-Amara-Jirlău, located in the southeast part of Romania (Fig. 2). These sites are one of the most important areas within the wintering range of Red-breasted Goose. The data within this study was collected between November and February in two seasons: 2018–2019 and 2019–2020. These three sites host between 2,000 and 10,000 Red-breasted Geese and between 100,000 and 300,000 Greater White-fronted gees every winter (SOR 2025).

Devices used

In our study we used AudioMoth devices (Hill *et al.* 2017), which is a small acoustic logger no more than 58 × 48 × 15 mm that can record sounds up to 384 kHz and is powered by 3 × AA batteries, ideal for our study aim. AudioMoth can detect gunshots from a distance of up to 500 m in broadleaf tropical rainforests (Hill *et al.* 2017). We tested the devices to see how far shooting sounds can be recorded at ROSPA0051

Figure 2. Location of the project sites included in the study area, where circle represent the study area of ROSPA0004 Balta Albă-Amara-Jirlău, triangle is the ROSPA0059 Lacul Strachina and square is the ROSPA0051 Iezerul Călărași.

Iezerul Călărași using the gun blast of a bird scare gun that runs on propane, and we found that in an open field the sound could be clearly recorded at distances of 1.5 km. For data gathering, devices were placed at distances of less than 3 km between them for overlapping coverage. AudioMoth comes without a protection case; thus, we used electrical junction boxes (IP55), ideal for protecting the device from water and offering a fastening system to fix the devices on trees (Fig. 3). A 5 mm hole was drilled in the lid of the box, right in front of the device's microphone, and was

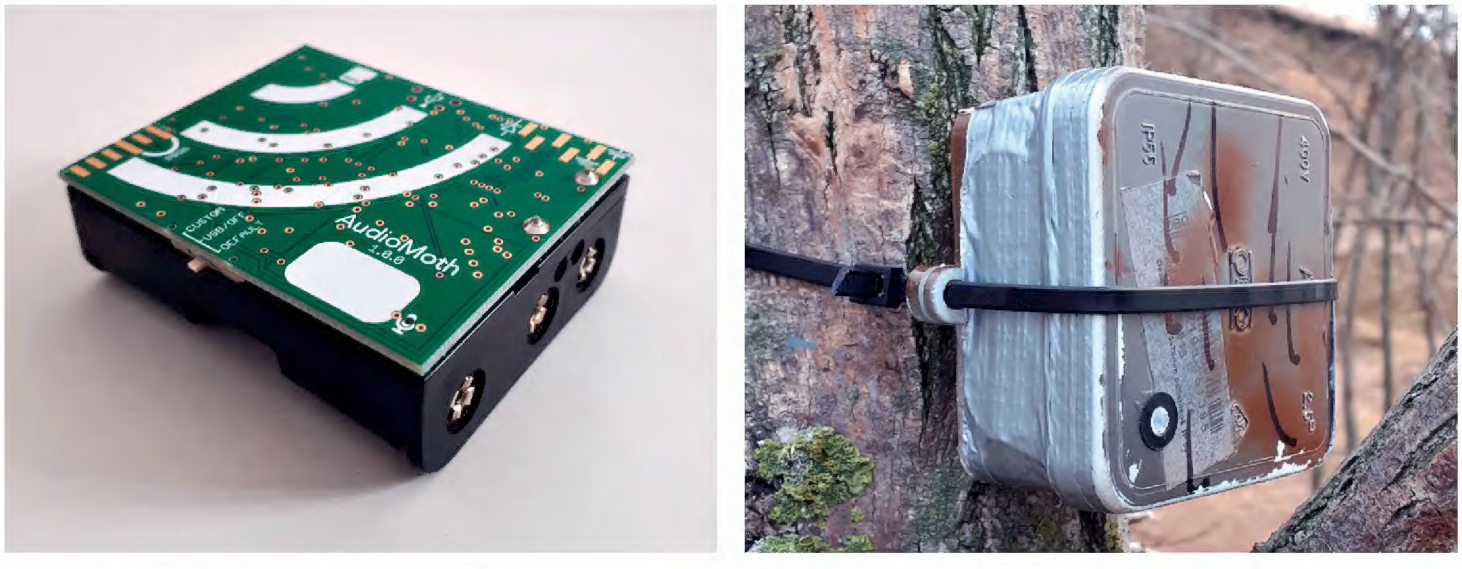

Figure 3. AudioMoth device and its waterproof case adapted from electrical doze box (IP55) and the waterproof acoustic membrane placed at the box (small black circle at the right image).

covered with a waterproof (IP67) acoustic membrane (https://voir.en.alibaba.com/product/60380452525-801219240/e_PTFE_acoustic_membrane_for_speaker_and_mic_IP67_waterproof_sticker.html). The waterproof acoustic membrane was replaced for every box re-used for the following field season. The number of devices per site was adjusted according to the size of the site, so they can cover as much of the geese roosting area. In total there were 12 AudioMoth devices used, 5 placed at Balta Albă-Amara-Jirlău, 4 at Iezerul Călărași, and 3 at Lacul Strachina at the same coordinates (coordinates might vary due to GPS accuracy, +/- 20 m) in each season 2018/2019 and 2019/2020 (Tab. 1). Due to unidentified circumstances, two devices were not found at their initial locations. The surface estimated to be covered by the devices was almost 60 km^2 (Fig. 4).

All devices were placed at trees situated between 1 and 708 m away from the shore of the lakes. The boxes were attached to the central trunk at a height between 4 and 6 m. All small tree branches that were at close distance to the box were removed in order to ensure that there would be no physical contact with the box.

Table 1. General data about the AudioMoths devices used during the study period November 2018 – February 2020

Box ID	Installation date	Latitude	Longitude	Project site	Last recording day	Days with records	Distance to the shore (m)
IC.1	15/11/2018	44.244783	27.249443	Iezerul Călărași	15.02.2019	92	60
IC.2	15/11/2018	44.236404	27.239373	Iezerul Călărași	14.02.2019	91	30
IC.3	23/11/2018	44.232057	27.259806	Iezerul Călărași	22.02.2019	91	3
LS.1	15/11/2018	44.670091	27.587817	Lacul Strachina	15.02.2019	92	33
LS.2	15/11/2018	44.68537	27.572165	Lacul Strachina	15.02.2019	92	142
LS.3	15/11/2018	44.685771	27.590112	Lacul Strachina	15.02.2019	92	76
BA.1	15/11/2018	45.29488	27.34769	Balta Albă	13.02.2019	92	53
BA.2	15/11/2018	45.294637	27.320368	Balta Albă	15.02.2019	92	36
BA.3	16/11/2018	45.30767	27.303613	Balta Albă	16.02.2019	92	77
BA.4	22/11/2018	45.2882042	27.3058939	Balta Albă	22.02.2019	92	1
BA.5	22/11/2018	45.281851	27.359527	Balta Albă	22.02.2019	92	120
IC.4	13/12/2018	44.228727	27.233662	Iezerul Călărași	27.02.2019	76	708
LS.4	05/11/2019	44.670048	27.587813	Lacul Strachina	02.02.2020	92	33
BA.6	05/11/2019	45.281796	27.359538	Balta Albă	21.01.2020	81	77
BA.7	05/11/2019	45.281801	27.359537	Balta Albă	02.02.2020	90	115
BA.8	05/11/2019	45.294664	27.320432	Balta Albă	29.01.2020	88	43
BA.9	05/11/2019	45.307677	27.303625	Balta Albă	05.02.2020	92	120
BA.10	05/11/2019	45.288068	27.305571	Balta Albă	21.01.2020	81	1
IC.5	07/11/2019	44.228727	27.233662	Iezerul Călărași	06.02.2020	91	708
IC.6	07/11/2019	44.244783	27.249443	Iezerul Călărași	07.02.2020	92	60
IC.7	07/11/2019	44.236404	27.239373	Iezerul Călărași	07.02.2020	92	30
IC.8	07/11/2019	44.232057	27.259806	Iezerul Călărași	28.01.2020	82	3

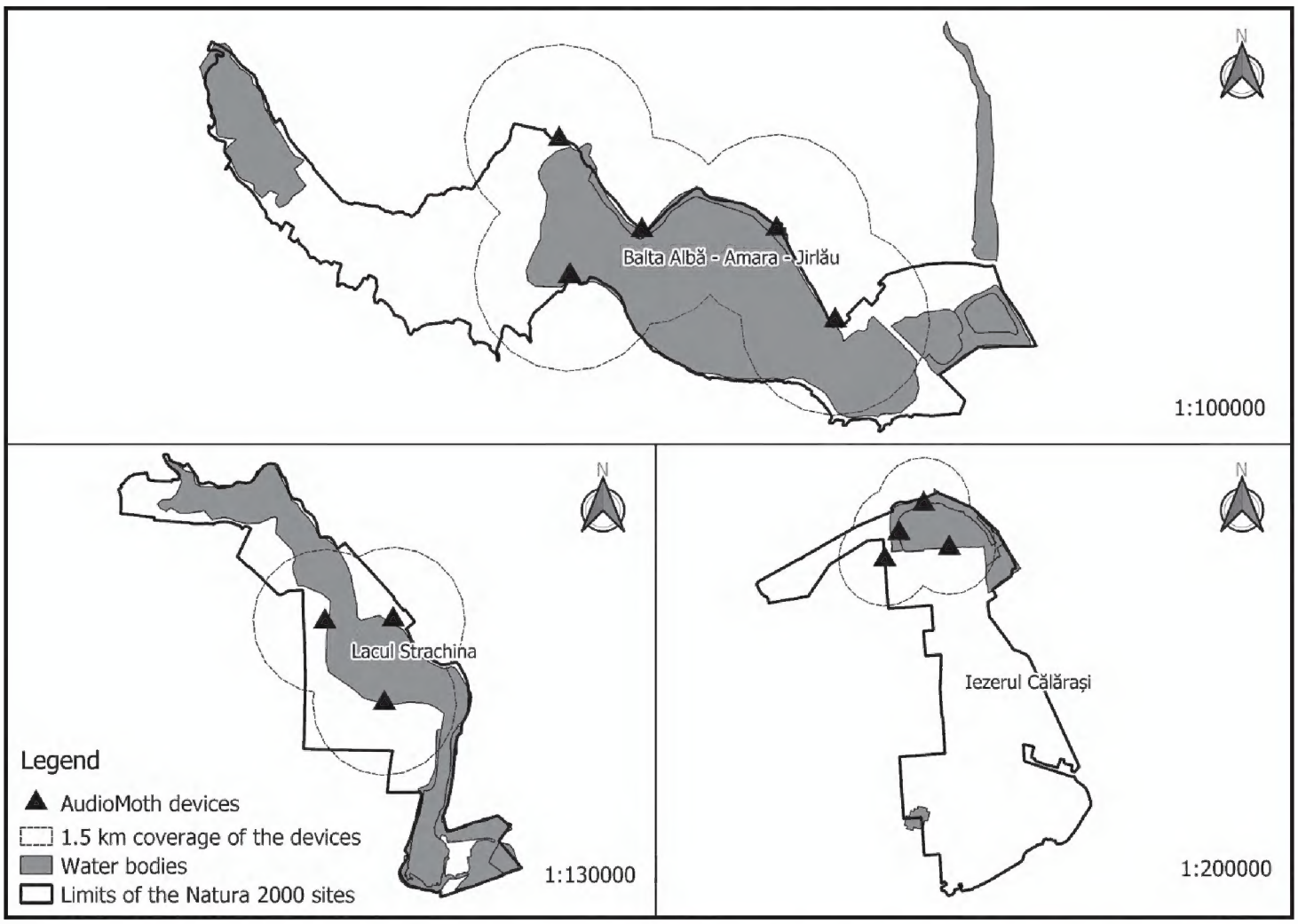

Figure 4. Location and coverage of the AudioMoth devices in the study areas during the study period November 2018 – February 2020.

Recording settings

The AudioMoth devices were configured using the AudioMoth Configuration Application (Hill et al. 2017) to record 3 hours from 6:00 AM to 09:00 AM every day at a sample rate of 16 kHz, a medium-high gain, with 0 seconds of sleep duration and 10800 seconds of recording duration, producing one 330 MB file at an energy consumption of 38 mAh each day per device. Devices were equipped with 3 AA lithium batteries, each of 1.5 v and 3000 mAh, offering power for more than 90 days. According to the calculation, the storage space of the 32 GB Micro CD card used was sufficient for 92 days, which is covering the whole winter season (November–February) when the geese are presented in the study area (Fig. 5).

Data analyses

In the first field season, between November 2018 and February 2019, 12 devices were deployed in the field among all three study areas, which recorded data from 276 days, 92 days for each study area. A total of 1,086 files were registered. In the second field season, between November 2019 and February 2020, 10 devices were placed among the study sites, working the same number of days, 276. A total of 881 files were collected. In both study periods, a total of 1967 files were collected, resulting in more than 5901 hours of recordings. Data accepted for further analyses was reduced

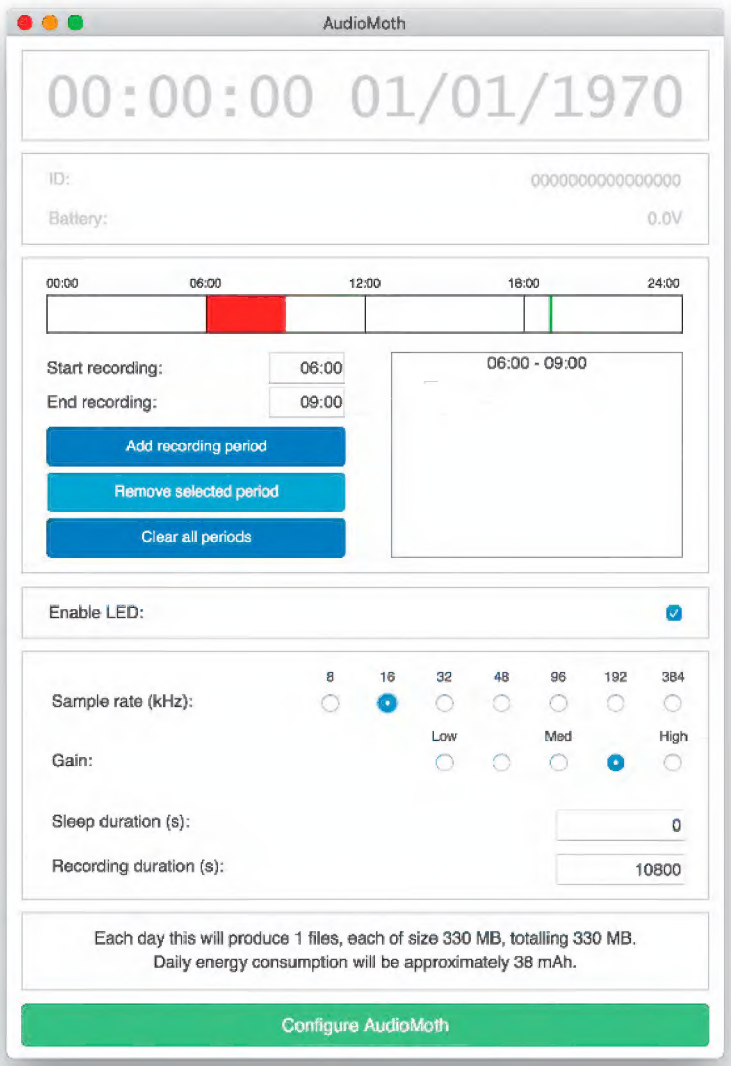

Figure 5. Configuration panel of the AudioMoth software application.

to 1237 files where data was found available. In the rest of the files were registered errors during the software data process or were not audible due to very strong noise, most likely from strong and permanent wind during the recording hours. Data was analysed using Kaleidoscope Pro software (v5.1.2; Wildlife Acoustics Inc., Maynard, USA) (hereafter 'Kaleidoscope'), which allows to sort, label, and identify different sound types, offering the possibility of batch analysis. Signal parameters used to detect gunshots were set at 4000–10000 Hz frequency range, 0.01–5 seconds length of detection, and a 0.35 seconds maximum intersyllable gap (Fig. 6). We took into consideration only the data classified into cluster 00 of the first 100 records as they are supposed to include the majority of gunshot detections with low false positive or false negative detections. For better results, we manually checked these 100 clusters 00 and excluded all false positive or false negative detections. All maps were done using ArcGIS 10 (ESRI 2011).

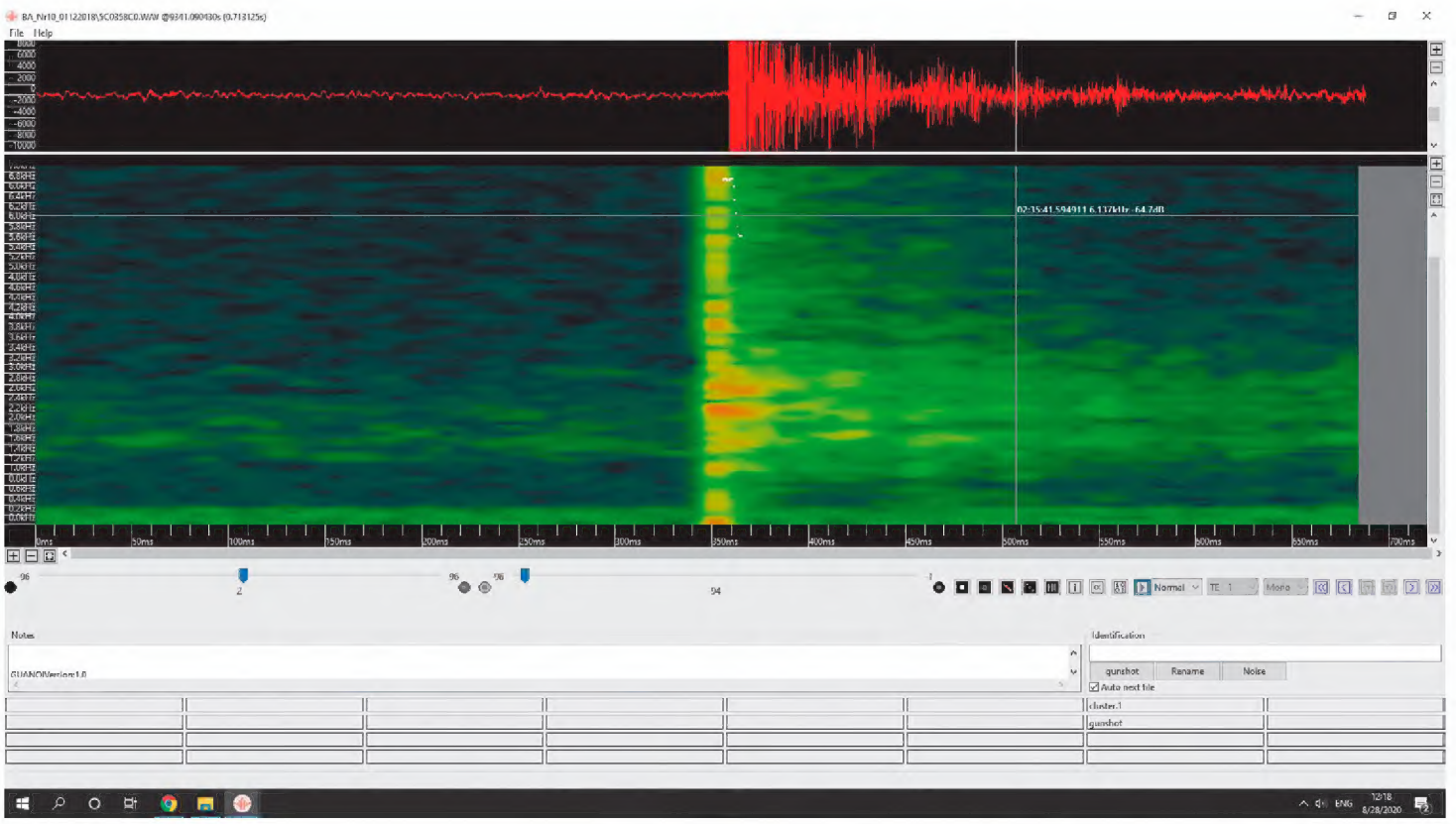

Figure 6. Spectrogram view of gunshot detected by AudioMoth and visualized by Kaleidoscope analysis pro software.

Results

During the study period November 2018 – February 2020, gunshots were registered in a total of 220 days out of 552 days. The mean number of gunshots registered per 3 hours between 6 and 9 AM during the days when hunting occurs in both study periods is presented in Table 2.

A total of 2530 gunshots were registered during this study. The weekends were among the days when most of the gunshots were registered, but at Balta Albă the hunting pressure seems to be almost constant during the whole week (Table 3), as the site is a well-known goose hunting area and, at the same time, one of the most important stopover and wintering sites for the Red-breasted Geese in Romania.

Table 2. Number of days with registered gunshots within the three study sites

Site	Registered days in the study period	Number of days with registered gunshots		Total	% of days with gunshots	Average number of gunshots registered per day
		November 2018 – February 2019	November 2019 – February 2020			
Balta Albă	184	62	65	127	69	15
Iezerul Călăraşi	184	18	57	75	41	7
Lacul Strachina	184	16	2	18	10	6
Total	**552**	**96**	**124**	**220**		

Table 3. Numbers of gunshots registered during the days of the week

Site	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total
Balta Albă	437	197	241	93	292	130	489	1879
Iezerul Călărași	137	109	77	75	26	42	84	550
Lacul Strachina	41	24	8	1	0	24	3	101
Total	**615**	**330**	**326**	**169**	**318**	**196**	**576**	**2530**

According to the months, the most numerous gunshots were registered in November and December, when is the peak of the goose migration over Romania, and in all three study areas the geese numbers are significant (Table 4).

The highest intensity was registered at ROSPA0004 Balta Albă-Amara-Jirlau, followed by Iezerul Călărași and Lacul Strachina, where the number of gunshots was the smallest among all three sites (Fig. 7). According to the data, in the western part of the Balta Albă Lake were registered the most numerous gunshots in three from all five devices installed around the lake. The highest number of gunshots registered in the 3-hour interval from 6 AM to 9 AM was 94.

Table 4. Numbers of gunshots registered within the months of the study period, 2018–2020

Month	2018	2019	2020	Total
January		180	248	**428**
February		116	0	**116**
November	372	1001		**1373**
December	400	213		**613**
Grand Total	**772**	**1510**	**248**	**2530**

Discussion

We consider that passive acoustic monitoring could be a valuable part of any research project, especially preventing wildlife crimes and optimizing law enforcement procedures in species conservation. The acoustic recorders in our study prove that the PAM methods are cost-effective, especially for gathering large amounts of data for biodiversity and how anthropogenic activities impact species populations and their behavior. An important role of PAM methods is that observer participation is eliminated, which saves time and costs, but also eliminates bias, especially in gunshot detection. However, recording quality might be obstructed due to unfavourable weather conditions such as strong wind, which combined with the position of the device (placed on trees) might bring serious misleading while proceeding with the data, e.g., false gunshots registered by the data analysis software. In our study, the data that was accepted for further analyses represents 62%. The reasons to remove the

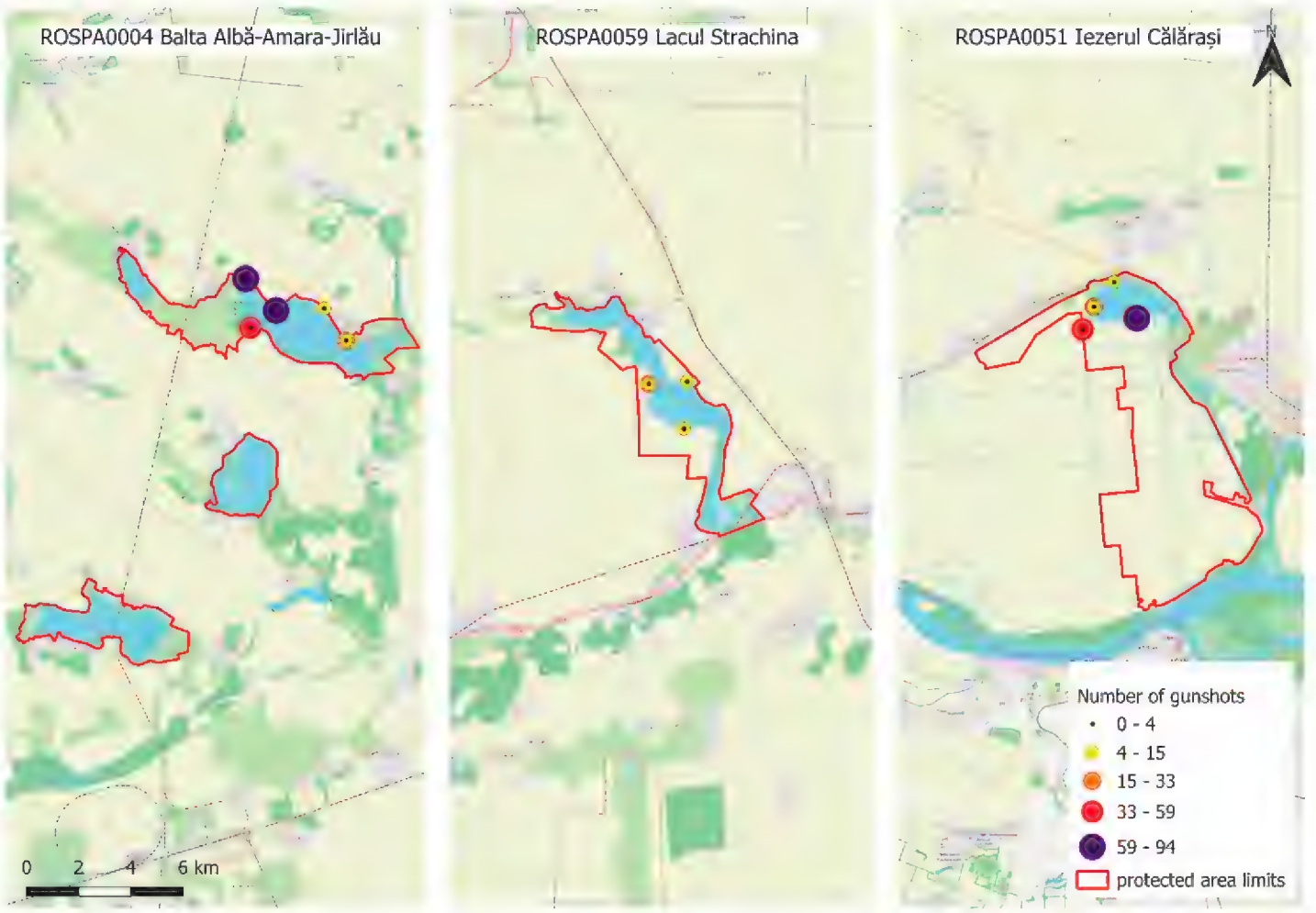

Figure 7. Intensity of the gunshots registered among the protected areas in the study areas during the period November 2018 – February 2020.

rest of 38% of the data collected are due to no data found due to an unknown error while processing the data with the software, 17%, and records excluded due to strong persisting noise during all duration of the record, most likely from strong wind, 21%. However, for the purpose of this pilot study, the data collected is representing more than a half, which in our opinion is sufficient to deliver reliable results.

In terms of technical performance during our study, we didn't face any technical failures during the study period, which was overlapping with the winter period, November–February. In the areas where the devices were installed, the winter temperatures might be a serious obstacle for such electronic devices charged with batteries and placed outside under harsh meteorological conditions. In order to protect the devices from water penetration, we have managed to isolate the box very well, which brings another valuable experience for further improvements in similar research studies. There were no signs of internal damage to the AudioMoth placed within the box due to water interaction. The only external damage we registered was on the waterproof acoustic membrane, which was punched in all 12 boxes used during both study periods. Possible explication about the membrane breakage is the exposure for a long period of time to freezing temperatures, which might bring deterioration of the membranes. The capacity of the microSD cards was complete exactly as it was programmed to last, between 90 and 96 days.

The Kaleidoscope Pro software was able to partially detect and extract the gunshots. In some cases, the software proceeds with many sounds as false positive gunshots, while in others the real gunshots were not registered. Most of the time, the sounds were coming from a probable hits of the tree branches with the trunk where the recording device was placed, especially during windy days.

The device we had used in this study was successfully tested that can register a gunshot with high level of confidence at a distance of about of 1.5 km. The exact distance from where the hunters were firing remains unknown, but our results indicate with a high level of confidence that the hunting in these three protected areas occurs mostly within the limits of these protected areas or in their vicinity, but not far away of 1,5 km. The hunting activity is resulting two principal threats: accidental shooting and high levels of disturbance, especially in the foraging grounds. The accidental shooting occurs when the hunters are not aware how to identify the species, its ecology in the wintering range and some other particularities about the species. Often the hunters from other regions in Romania or hunting tourists from abroad are not informed by the hunting associations about the species presence at the time when they hunt. Deliberate killing is rare, but still occurs in some regions, especially in Bărăgan and the coastal areas along the Black Sea. The disturbance causes a considerable increase in energy consumption due to the stress, thus resulting more frequent flights and reduced energy intake due to the short feeding time. For example, an anthropogenic disturbance during the night causes the whole flock of geese to leave the roost, forcing them to spend a long time in flight in search of other places to rest. At the individual level, this results in a weaker body condition, increasing the risk of mortality due to hunger and generally poor health. It can also have cumulative effects by delaying or prolonging migration, as geese do not have sufficient energy reserves or reduced reproductive productivity if birds arrive at the breeding site later or in poor condition.

The results of this study have already been reflected in specially designed measures included in the National Species Action Plan for the Conservation of the Red-breasted Goose in Romania, approved by Ministry Order No. 2480/16.09.2022. These measures include a restriction on hunting within 300 meters of all water bodies located within the boundaries of the 40 SPAs designated for the species in Romania (Todorov 2022).

Balta Albă Lake

Is one of the most important lakes for the Red-breasted Geese situated in the northern part of the Bărăgan region, south east part of Romania. It is not a surprise that the number and intensity of the gunshots are higher in this study area, as the lake is a well-known goose hunting ground due to the biggest concentrations of the Greater White-fronted Goose, which is a game species according to the national hunting list (Law 407/2006). At this site, the Red-breasted Geese, which in some years can reach up to 8,000 – 10,000 individuals, are mixed all the time with the Greater White-fronted Geese, and chances for accidental or deliberate killing are very high. The geese usually roost in the western part of the lake, where exactly three of the AudioMoth devices registered the most numerous gunshots during the study period.

Since 2015 exactly this area was designated by the local hunting association as a free hunting area. Unfortunately, during the years this rule was rarely respected by the hunters, and our results show exactly that in the western part of the lake, where the geese prefer to roost, the hunting pressure was very high. The Balta Albă's lakeshores offer suitable landscape features where the hunters are usually hiding and shooting when the geese take off early in the morning, thus chances for accidental shooting of the Red-breasted Geese are very high. The mean number of gunshots registered in this area was 15 per 3 hours of recording between 6 and 9 AM. The highest number of gunshots registered was 94 gunshots in a single day. In this area, the foraging grounds of the geese might vary from 1 km to 30 km away from the lake, mostly of the time at 4–5 km away. The fact that the gunshots were registered means that the firing took place around the lakeshore at a distance between 0 and 1,5 km away. All five devices were placed exactly at well-known places where the hunters are firing when the geese take off from the lake in the mornings.

The hunting was performed with high intensity on all days of the week, but especially during the weekends. The fact that the most numerous gunshots were registered in the western part of the lake, preferred by the geese and at the same time called by the hunters as a free hunting area, is raising serious concerns about the application of the conservation measures proposed by the hunters.

Iezerul Călărași

Lake Călărași is the most important goose area along the Danube River between Romania and Bulgaria, holding up to 5,000 Red-breasted Geese in recent years. The protected area of which the lake is part has a management plan approved, and special goose conservation measures are included (SOR 2025). Since 2010, the local hunting association has agreed by themselves to introduce no hunting area around the lake. However, our data shows that the hunting occurs along the southern shore of the lake, exactly in the direction of which the geese usually take off during the morning.

Strachina Lake

This lake is another important area holding significant numbers of wintering geese. The gunshots within the limits of this protected area are much less compared with the other two project sites, most likely because at Strachina there is an approved management plan (OM No. 842/2016), and one of the key goose restrictions is no hunting area 100 m away from the lakeshore. This management restriction is relatively respected by the hunting association that administers this area, and most likely the small number of gunshots are due to better knowledge of the hunters about this restriction (SOR 2025).

Conclusions

We consider that the AudioMoth devices used in our study are offering a sufficient and reliable way of registering the gunshots produced during the goose hunting activity. By using PAM, we can collect valuable data that can serve as background for introducing conservation measures in order to protect the vulnerable Red-breasted Goose, but also the Lesser White-fronted Goose, vulnerable species, and lookalike species with the Greater White-fronted Goose. At the same time, the devices can be used as tools to identify the geese presence in certain areas, e.g., remote and inaccessible areas, which can contribute to discovering new stopover or wintering areas, and the time spent at these areas.

Certainly, one of the main advantages of this device is that it can be used to identify poaching activity as it is already used in many other cases across the globe (Lopez-Tello and Muthukumar 2018; Wrege et al. 2017).

Important advantages of the AudioMoths are that they have small dimensions, which helps to be hidden very well in the field.

The energy consumption has shown very good performance. In our case, the batteries we used (Energizer Ultimate Lithium) allow us to collect data in relative low temperatures during the winter period for more than 90 days, during 3 hours of recording. When we measured the batteries at the end of the deployment period, we have found that they were not drained.

In order to assess how hunting activities can be monitored by using PAM devices, we have decided to present in this manuscript only the preliminary results regarding the deployment and the efficiency of the PAM devices. We are fully aware that the data analyses and the results could contain some sort of bias, but being a pilot study we consider it important to present these preliminary findings as a basis for future, more comprehensive research.

Recommendations for the field data collection

The device should be placed in a way that eliminates any bias in sound data collection, which will ensure much more accurate gunshot data extraction. In order to avoid double counting of the gunshots recorded from different AudioMoth devices, we recommend using only one device, which must be placed within the borders of the protected area and mounted on a pylon. This will limit the chances of recording noise from different objects that might hit the pylon while recording, for example, shaking tree branches that are hitting the recording box if the device is placed on a tree branch.

Recommendations for data analyses

Further research into automatically extracting gunshots with a high level of confidence requires significantly more attention from scientists developing software to analyze and cluster different sounds.

Recommendation for conservation measures

In order to reduce the main threats caused by the hunting activity, accidental/deliberate shooting and the high level of disturbance, we recommend legislative modifications, such as:

- Complete hunting ban within the limits of the protected areas that are designated for the conservation of the Red-breasted Goose in south-east Romania;
- Temporal hunting ban within the sites when significant numbers of geese are registered across the winter period;
- Hunting only on certain days, Friday to Sunday, in order to minimize the intensity;
- Intense anti-poaching patrols and control of the hunters;
- Disseminating information on the hunting restrictions among the members and guards of the hunting associations in each hunting ground;
- Training courses for hunters and environmental protection guards;
- Installation of information panels with hunting regulations and restrictions.

We consider it is necessary to continue with data collection on hunting pressure and illegal killing of protected waterfowl species along the flyway. Additional data such as number of hunting goose permits issued, hunting bags, along with survey on the identification skills and knowledge of the hunters on the protected and game species could offer valuable information about further legislative needs. This information, correlated with the data from the PAM, can contribute significantly to ensuring a favorable conservation status of the protected species by eliminating certain anthropogenic pressures and threats.

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